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Shock waves in magneto-gasodynamic turbulence

By S.A.Kaplan

The spectral theory of isotropic magneto-gasodynamic turbulence proposed by the author some years ago (1,2) gives the following expression for the spectral functions of kinetic and magnetic energies:

a) Stationary case:

$$F(K) \sim \frac{V_K^2}{2K} \sim K^{1-2\alpha}, \quad G(K) \sim \frac{H_K^2}{8\pi\rho K} \sim K^{1-2\alpha} \quad (1)$$

$$\alpha = 1 - \frac{3}{4}\frac{x_f + x_g}{\zeta_f - \zeta_g} + \sqrt{1 + \frac{1}{2}\frac{x_f + x_g}{\zeta_f - \zeta_g} + \frac{9}{16}\left(\frac{x_f + x_g}{\zeta_f - \zeta_g}\right)^2} \quad (2)$$

b) Quasistationary case:

$$F(K) \sim \frac{V_K^2}{2K} \sim K^{1-2\alpha}, \quad G(K) \sim \frac{H_K^2}{8\pi\rho K} \sim K^{1-\alpha} \quad (3)$$

$$\alpha = 1 - \frac{3}{4}\frac{x_f}{\zeta_f} + \sqrt{1 + \frac{1}{2}\frac{x_f}{\zeta_f} + \frac{9}{16}\left(\frac{x_f}{\zeta_f}\right)^2} \quad (4)$$

where $k = 2\pi/\ell$ —wave number of eddies, or motions of scales ℓ, v_k and H_k – velocity and magnetic field of motions in these scales. $F(k)$ and $G(k)$ – spectral functions of the

kinetic and magnetic energies, respectively. In other words F(k)dk and G(k)dk are the quantities of the kinetic and magnetic energies per unit mass contained in the motions with wave numbers in the interval from k to k+dk, ρ - gas density ζ_f and ζ_g numberless quantities describing the full dissipation of the kinetic energy and the increase of the magnetic energy in shock waves. Therefore $\zeta_f - \zeta_g$ describes the dissipation of the kinetic energy of shock waves into thermal energy. $\mathcal{X}_f$ and $\mathcal{X}_g$ are also dimensionless quantities describing the transfer of the kinetic energy and, respectively, the magnetic energy from big scale to lesser motions (the inertial members of the magneto-gasodynamic equations).

If the dissipation of energy in the shock waves at magneto-gasodynamic turbulence is unimportant, we have $\mathcal{X}_f + \mathcal{X}_g >$

$$> \zeta_f - \zeta_g \qquad \text{or} \quad \mathcal{X}_f \gg \zeta_f \text{ and therefore } \alpha \to 4/3$$

We obtain then the Kolmogorov's spectra for the kinetic and the magnetic energies

$$F(K) \sim K^{-5/3}, \quad G(K) \sim K^{-5/3} \qquad \text{(stationary case)}$$

$$F(K) \sim K^{-5/3}, \quad G(K) \sim K^{-4/3} \qquad \text{(quasistationary case)}$$

On the contrary, if the dissipation of energy in shock waves is larger than the transfer of energy between the motions of different scales, we have $\mathcal{X}_f + \mathcal{X}_g \ll \zeta_f - \zeta_g$ or $\mathcal{X}_f \ll \zeta_f$ Therefore $\alpha \to 2$ and we obtain

$$F(K) \sim K^{-3}, \quad G(K) \sim K^{-3} \qquad \text{(stationary case)}$$

$$F_{(K)} \sim K^{-3} \; , \; G_{(K)} \sim K^{-1} \qquad \text{(quasistationary case)}$$

From this it follows that in the magneto-gasodynamic turbulence, in which the shock waves are taking place, the dependence of the velocities of eddies upon the scale ℓ of motions is as follows:

$$\frac{1}{3} \leq \frac{d \ln V_\ell}{d \ln \ell} \leq \frac{1}{2} \qquad (7)$$

The magnetic fields H_e depend upon the scale of field fluctuations in such a way:

$$\frac{1}{3} \leq \frac{d \ln H_\ell}{d \ln \ell} \leq \frac{1}{2} \qquad \text{(stationary case)} \quad (8)$$

$$-\frac{1}{3} \leq \frac{d \ln H_\ell}{d \ln \ell} \leq 0 \qquad \text{(quasistationary case)} \quad (9)$$

The quasistationary case of magneto-gasodynamic turbulence corresponds Batchelor's picture of magneto-hydrodynamic turbulence, in which the magnetic energy is chiefly contained in small scale motions.

The increasing rôle of energy dissipation in the shock waves results in an increase of the index of the degree of spectral functions.

The author has tried to find the dependence of the vlocity and the magnetic field upon the scale of motions in the interstellar space. An analysis of the radial velocities of interstellar gas clouds shows that up to 80 parsecs (3):

$$\frac{d \ln V_\ell}{d \ln \ell} = 0.36 \qquad (10)$$

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which is in good accordance with (7). Respectively, an analysis sis of the observational data of interstellar polarization shows (with great uncertainty) that

$$\frac{d \ln H_\ell}{d \ln \ell} \approx 0.12 \qquad (11)$$

This value does not agree with (8) or (9), but it is necessary to keep in mind that in this case the observational dependence does not coincide with the actual dependence, because we do not take into account the single value of H_e, but the average for some hundred parsecs on the line of sight. If this effect is duly taken into account, we get

$$\frac{d \ln H_\ell}{d \ln \ell} \approx -0.38 \qquad (12)$$

which also does not agree with (8) or (9). In view of the uncertainty of this value this difference does not seem to be very serious. It is interesting to note that the observational data are favourable in the case of quasistationary turbulence.

Both (10) and (12) are nearer to the lower limits of the indices of the degree of turbulent spectrum - therefore the dissipation of shock wave energy in the interstellar turbulence is unimportant.

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To the problem on the mechanism vpf the origin of stars
in stellar associations

By V.A.Ambartsumian

Almost ten years had passed since the idea about stel-
lar associations as non-stable stellar systems had been
formulated. The ~~totality~~ of data obtained during this time
by means of observations ~~serves as an evidence of the fact~~
that stars contained in the associations are young objects
of some million years of age. We would like to ~~maintain~~
that this concerns both the O and T associations. It is
also known that O-associations, which could be sufficiently
investigated in this respect contain, as a rule, T Tauri
type stars and are consequently T associations also. There
are, on the other hand, T associations, which do not con-
tain hot giants. But apparently the mechanism of stellar
formations must be similar in O and T associations. This
means that if we shall be able to formulate the theory of
stellar origin for a given type of associations; this theo-
ry should admit variations, which will enable an explana-
tion of the origin of stars in associations of ~~some~~ other
type.

Two hypothese ~~connected with~~ on the origin of ~~the~~ stellar
associations had been discussed up to the present: One
of them suggested by the author ~~which~~ at the initial stage
of the idea about associations ~~suggested~~ supposes that ~~stars~~
~~forming some expanding group have~~ originated as a result of
~~an~~ expansion from a body or a system, the volume of which
was initially very small. The dimension of the latter was
in any case less than one parsec. According to this point
of view, these initial bodies (protostars) were either not
observed up to the present, or were not yet identified ~~by~~
with any known ~~known~~ objects. ~~~~. This point of view does not
give any indication about a concrete mechanism of stellar
origin, postponing its explanation up to the moment, when
the earliest stages of the expansion of the association
could be studied in details.

On the other hand, Oort[2] and Oort-Spitzer[3] suggested a very interesting mechanism of the influence of radiation of O stars on large gaseous clouds in their surroundings. This mechanism leads to a possibility of transformation of a part of the radiative energy of the stars into kinetic energy of interstellar gaseous clouds. It seems to us that the role of the mentioned mechanism in the total balance of the kinetic energy of interstellar matter is really important. According to Oort in the cold H I regions, which surround the H II zone, formed around an O star, a very high gas pressure can arise, which may lead as a result of condensation to the origin of stars, when the limit of gravitational instability is passed. Oort's views were reported at the 2nd Symposium on gaseous dynamics of cosmical clouds and we shall not them here in details.

It seems, however to check how much this hypothetic mechanism of the origin of stars is responsible for the formation of real associations. We shall for this purpose data, related large gaseous clouds, the structure of which is regular to a certain extent. It seems to us that a choice of such clouds quasi-regular structure may be of interest from the point of view that the mutual relations between stars and the diffuse matter in them must be of greater simplicity and more plausible, than in the cases of a quite irregular structure which does not permit to reveal the spatial geometrical configuration of the nebula around NGC 2244, around IC 1805[5] and the large ring around λ Orionis[6].

It is essential that in each of them a cluster of stars of early spectral classes is located. In the two first nebulae these clusters contain several O type stars and only one O star in the latter case. The angular dimensions of the nebulae and of the central cluster are given in the following table:

Nebula	Diameter of the nebula	Diameter of cluster
NGC 2244	70'	25'
IC 1805	95'	12'
Ori	250'	30'

The diameter of the cluster is small in all three *sufficiently* as compared with the diameter of the nebula . Therefore, it is out of the question that the ~~stars of the~~ cluster *stars* could have originated at the periphery of the corresponding nebula. On the other hand, it is evident that all the stars of the cluster are genetically connected with the O-stars of the cluster, which are causing excitation of the corresponding nebula. As the age of the O-type stars does not exceed several million years there arises a question whether an explanation of the origin of the cluster, the age of which is of the same order, can be given.

In other words, one must take into consideration that quite recently an intense process of stellar formation had taken place in the central region of each of the mentioned systems. This process is perhaps continuing *ning* still at present: I would like to draw attention to the fact ~~mentioned~~ *mentioned* by Markarian in 1950[7] ~~concerning~~ *concerning* the presence of a multiple Trapezium type system inside the cluster IC 1805 around the O-star HD 15558. According to the data by Sharpless[8] this nucleus contains about 15 stars. As it had been mentioned by us earlier[9], the systems of the Orion Trapezium type must be very young formations. Their age must be of the order of one million years and even less. It may therefore be supposed that the process of stellar formation is going on in IC 1805 still at present, but that this process takes place in the centre of the cluster. As ~~regards~~ *regards* star formation on the periphery of the above nebulae; there are no direct data to suppose it.

On the other hand cases are known to us, when open clusters containing O type stars are not stable and must expand with time. Thus for instance; direct signs of expansion were established bw Markarian in respect to IC 2602[10]. According to the last paper by Hopman the cluster IC 4996[11], which is similar to the central part of IC 1805 cluster is distinguished by large internal motions; which proove its instability

It is not excluded that O clusters located in the central parts of the mentioned nebulae can expand in the same way. In this case after one or two million years these clusters will convert into expanding scattered groups, similar to the association around ζ Persei. Under these conditions the assumption about the origin of stars of expanding associations in the HI regions of symmetrical nebulae is superfluous.

Thus the data obtained from observations permit to draw the following approximate picture: Each investigated formation represents a large diffuse nebula; or a complex of nebulae; which cannot remain in equilibrium. The assumption about an expansion of these nebulae is quite natural and their age must be evaluated as two-three million years. In the central part of such a nebula a cluster is present, the age of which is of the order of one-two million years. Besides, there exist in some cases these clusters stars of stellar groups, the age of which must be less than one million years.

When considering this condition from the point of view of the cosmical scale of time we may say that the age of the nebula and the cluster in the above systems are of the same order. It is quite probable accordingly that the formation of the nebula and the cluster occurs at the same time and as a result of a single cosmogonical process. The expansion of the nebulae forestalls somewhat the expansion of the cluster. This forestalling is caused by the fact that the stars of the central cluster are originating somewhat later. We do not exclude the possibility that some stars could originate with the nebula itself, and even before the formation of the nebula and had therefore time enough to withdraw from its central regions. This possibility must be studied.

Of considerable interest is the discovery by Menon[12] of the expanding cloud of neutral hydrogen in the region of the star η Orionis: In the central part of this cloud hot stars are absent: They had either left this part of the nebula (in this case this must have been AE Aurigae, μ Columbae and 30 Arietis, possessing the same centre of expansion), or their formation may take place there in future. In both cases our conclusion that the hot stars and the nebula do not originate si-

multaneously is confirmed.

Thus, instead of the traditional formulation of the problem about the origin of stars or stellar groups from a nebula, we are lead ~~as it seems inevitable~~ by observational facts to the problem about the joint (although not quite simultaneous) origin of stars and of nebulae out of some objects of unknown nature.

As concerns the mechanism of the formation of stars and nebulae; there exist; as it seems to us, only one way - it is the study and a comparison of different groups of young stars. I should like in this connection to mention shortly some peculiar formations of this kind. I have stellar chains in view.

The question that stellar chains are met in studying stellar distributions much more frequently, than it should be expected according to the random law was raised many times by ~~different investigators~~. The papers by Oberguggenberger[13], Fessenkov[14] and Martynov[15] can be mentioned in this connections. I consider here only the chains of ~~early type~~ stars in stellar associations and should like to draw attention to the indisputable reality of some of these chains. I shall give three examples, every of which is striking and deserves special investigation.

I. <u>Orion belt</u>. This is, indeed, an example of a stellar chain, which is known for the longest time. The exceedingly high luminosity of all three ~~objects~~ supergiants and small differences ~~belonging to a~~ between them ~~very narrow interval of~~ spectral types, makes the hypothesis about the random ~~arrangement~~ grouping of these objects quite improbable. One may state with almost absolute certainty that this triple system of exceptional ~~supergiants~~ supergiants is of a joint origin. Their chain configuration is therefore of a particular interest:

2. Chain of O-BO type stars in NGC 6823 cluster first mentioned ~~studied~~ by Markarian[16]. According to Sharpless[8] this chain (BD + 22°3782) consists of three multiple, Trapezium type systems of very compact stellar groups. This trapezium ~~chain~~ is located in the centre of the cluster and ~~the~~ nebula NGC 6823 and its ~~random origin~~ explanation by ~~accident~~ is out of the question. On the background of the nebula NGC 6823 numerous remarkable veins of dark matter of elephant trunk type are observed. According to Shajn the direction of the dark veins must coincide with the direction of ~~the magnetic lines. It is of interest therefore~~ ether the

direction of the ~~chain~~ *stellar* chain BD +22°3782 coincides with the direction of these veins. This might give some indications about the mechanism of the origin of this ~~after~~ chain. However these *two* directions are almost perpendicular. It must be underlined that the mentioned chain lies in the centre of a large gaseous nebula, the diameter of which is of the order of 20 parsecs, thus ~~we~~ *in this can also a situation similar* have ~~namely the position analogous~~ to that given at the beginning of the present communication. The length of the chain being less than one parsec.

3. The third ex~~am~~ple ~~belongs~~ *is not related,* to hot stars. We have ~~namely~~ in view the chain of Herbig-Haro objects in Orionis. It seems probable at present that each of these objects contains a group of young dwarfs. Thus, we have in this case also a chain consisting of groups reminding the trapezium type systems. Contrary to the second example, we meet *here* cold dwarfs ~~here~~, but not hot stars.

The existence of a number of other chains of hot giants was established both in our Galaxy and in M-33.

It seems to us that the fact of the probable appearance of chains of individual giants (or supergiants) and of chains of close stellar groups is of great cosmogonical importance and indicates one of the ~~probable~~ directions, which should be followed in the study of the real mechanism of stellar formation.

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Examples of gas motion and certain hypotheses on the mechanism of stellar outbursts

By L.I.Sedov

Summary

In connection with the problem of explanation of stellar outbursts exact solutions of the unstationary gas motions with spherical symmetry can be given in the following three cases:

I. Propagation of detonation waves from the interiors to the surface of a star, accompanied by an output of nuclear energy on the wave front. Effects of the increase of detonation velocity depending upon the law of density decrease from the centre to the outer layer (failure of Chapman-Jugue's rule) are investigated. As a result of sufficiently rapid density decrease one obtains a complete dissipation of detonation gas products with a formation of vacuum near the centre.

Similar solutions are obtained for the spherical problem of the propagation of a rarefication jump, accompanied by an energy output (a jump of the flame front type) through the gas at rest.

2. Perturbed gas motion due to an explosion caused by a sudden output of a considerable amount of energy inside the star. This energy is transferred to the surface together with the shock wave. Exact axternodal solutions of equations of the adiabatic unstationary gas mo-

tions, accompanied by a formation of vacuum when
$$\gamma = \frac{C_P}{C_v} = \frac{4}{3}$$
and without it, gravitation being taken into account, are given. Some solutions for large values of γ are studied.

3. Examples are given of dynamically unstable equilibrium states disturbed by an explosion followed by the origin of a shock wave, propagating through the gas with variable density at rest. Motion without any energy output is developing. The energy of the disturbed motion at any time is equal to the initial energy at the equilibrium state.

The application of the obtained results for an interpretation of the observational data requires an additional investigation of unstationary effects in stellar photospheres.

Besides that an investigation of the rôle of electromagnetic effects in star outbursts is needed.